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## Reply to 'Comments on `` Suppressing impact of the Amazonian deforestation by the global circulation change''


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## Reply

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**T**he major objective of Chen et al. (2001) was to report global circulation changes over the last 40 years that have increased moisture convergence over Amazonia. Diagnostic analysis of reanalysis data revealed global circulation patterns of critical importance to the hydrological cycle of the Amazon that have been neglected by all numerical simulations of the Amazonian deforestation.

Chen et al. summarize several Amazonian rainfall studies and note that precipitation trends in this region are opposite to predictions of numerical models that have been used to investigate the effects of deforestation. Their analysis of surface data from the region revealed that precipitation, surface pressure, and surface temperature all were consistent with previous analyses. They found changes in outgoing longwave radiation over the Amazon were also consistent with trends of increasing rainfall.

By examining *global-scale* convergence and global-scale water vapor convergence patterns in observed data (not models), Chen et al. found clear evidence that global-scale circulation fields are moving more moisture into the Amazon basin now than in the middle of the twentieth century. A comparison between the trend of the Amazonian hydrological cycle (Fig. 2. of Chen et al.) and the interdecadal change of global divergent water vapor flux and precipitation (Fig. 3 of Chen et al.) led them to conclude that the increase in precipitation is primarily attributed to the interdecadal changes of the global atmospheric cir-

ulation in the past four decades. Furthermore, examination of Fig. 3 of Chen et al. reveals a complicated global convergence–divergence pattern and not one with large convergence over the Amazon and weak divergence everywhere else (cf. the global “conveyor belt” in ocean circulation, for instance) as would be suggested if Amazonian deforestation were the sole cause of the global pattern. Evidently, long-term changes outside Amazonia, and likely not strongly connected with Amazonia, have contributed to this observed convergence. Chen et al. concluded that future studies of impacts of land-use change in the Amazon cannot simply ascribe *regional* changes in the hydrological cycle to regional land-use changes because global circulation has increased moisture flow to this region over the last 40 years. They did not attempt to pin down the reason for the observed changes in the global circulation.

Commenting on the observed Amazon precipitation trends, Henderson-Sellers and Pitman (2002, hereafter HP) state that “Chen et al. (2001) do not suggest any mechanism for these changes except interdecadal variability.” We specifically say that “interdecadal changes in Amazon basin rainfall and hydrological cycle evidently are strongly linked to changes in the global divergent circulation.” In other words, an increase in water vapor convergence into the region over the last 40 years (a result not disputed by HP) must be the starting point for all analysis of the hydrological cycle for the region. One cannot accurately explain changes over time of processes going on inside a box without first specifying changes over the same time of what is going in and out of the box. Henderson-Sellers and Pitman discuss various aspects of *regional* changes that also certainly contribute to changes in the hydrological cycle of the region. We agree. This was not the purpose of Chen et al.’s paper.

Henderson-Sellers and Pitman state that “Henderson-Sellers et al.’s (2002) third isotopic result agrees with about half the published deforestation predictions (Zhang et al. 2001) but disagrees with Chen et al.’s (2001) results since decreased runoff would not be expected with increased atmospheric moisture convergence.” It would be more convincing if HP had directly compared each indicator (isotopic

results and global convergence) with measured runoff rather than with each other. In the absence of such a comparison, we can only speculate since “the Amazon recycles about half of its water within the basin” (Henderson-Sellers et al.). As inferred from the increasing trend of interdecadal precipitable water within the Amazon, the increase of water vapor convergence over this basin may accelerate water recycling and maintain the precipitable water increase, rather than enhance basin runoff.

Henderson-Sellers and Pitman “believe that local intensification of mesoscale circulations and changed surface water amounts may both contribute to differences between simulations and observations in Amazonia.” How such factors contribute to these differences is beyond the scope of Chen et al.’s study. However, some discussion in response to HP’s comment concerning this issue would be informative to future research on Amazon deforestation.

Model simulations of mesoscale circulation over heterogeneous surfaces suggest that vegetation breezes may reach the sea-breeze intensity, but no such strong circulations have been observed (e.g., Segal and Arritt 1992; Hubbe et al. 1997). The clear-cut swath features of deforestation in the Amazon forest may likely generate vegetation breeze circulations. However, the potential role in rainfall enhancement played by these features needs to be confirmed by observations. Based on the present percentage of forest clearing, the area affected by vegetation breeze is no more than 10% of the Amazon forest area. Let us assume that the mesoscale circulation induced by surface heterogeneity may result in a meaningful rainfall increase to the Amazon basin. Enhanced rainfall due to the vegetation breeze would be limited to a relatively small portion of the Amazon basin. In order to affect the interdecadal trend of the Amazon rainfall, the vegetation breeze circulation must generate a large rainfall increase over the cleared regions. But such a rainfall increase over these regions likely would stimulate reemergence of substantial vegetation that eventually suppresses the vegetation breeze. In addition, during the wet season, the persistent wet soil may suppress the formation of vegetation breeze circulations. Furthermore, such mechanisms do not explain the attendant interdecadal decrease in surface pressure over this region reported by Chen et al. More quantitative results are needed to confirm HP’s assertion that a substantial rainfall increase is caused by the surface heterogeneity.

Land surface parameterization is considered by HP as a likely source of transpiration errors in GCMs, particularly effects of surface water. In his 1995 pa-

per Bonan (1995) shows that, compared to fully vegetated grid cells, the inclusion of lakes and rivers causes latent heat flux to increase during June, July, and August, and decrease in other months for tropical forests. In South America the magnitude of the difference in July is generally less than  $10 \text{ W m}^{-2}$  (Fig. 6 of Bonan), which is less than the tropical forest average of about  $40 \text{ W m}^{-2}$  (Fig. 2 of Bonan) likely because of the relatively low percentage of open water in the Amazonian region (Fig. 1 of Bonan). Based on an unpublished report by Cogley (1998), HP argue that “Bonan’s estimates of grid cell water, at least for Amazonia, may have been incorrect.” No justification is given for the assumed veracity of an unpublished report over a peer-reviewed paper.

Henderson-Sellers and Pitman state “we suggest that there is a problem for Chen et al. (2001) in failing to compare like with like. Specifically we believe that there are a number of factors likely to be confounding recent observations of meteorological changes in the Amazon basin . . . .” They list 1) global warming, 2) mesoscale circulation enhancements caused by local heterogeneity, and 3) inadequate representation of seasonality of, and feedbacks from, surface water. The effect of global warming, if any, over the last 40 years is included in the observed global-scale trends Chen et al. reported and therefore do not present any problem. Items 2 and 3 represent regional factors that superimpose on the global changes. Since the regional trends in surface observations and outgoing longwave radiation are in agreement with the global trends in water vapor convergence, the regional effects suggested by HP must be either of the same sign or else of lesser magnitude than the effect of global circulation change. None of these confound the global analysis and therefore do not represent any “problem for Chen et al. (2001) . . . .”

Also HP pointed out that increasing greenhouse gases may reduce the disparity between the deforestation scenario and the actual rainfall decline. It may be possible that a global model response to greenhouse warming may generate the global circulation changes shown in Chen et al.’s Fig. 3. We strongly suggest that Henderson-Sellers and Pitman check into this possibility. Furthermore, Ropelewski and Halpert (1987, 1989) showed that the interannual variation of tropical South American rainfall is closely linked to the ENSO cycle by being enhanced (reduced) during cold (warm) ENSO events. Henderson-Sellers and Pitman provide a list of their potential future research relating to deforestation. Based upon their rainfall isotope study, it may be of interest for them also to explore the effects of ENSO

cycle interactions with deforestation on Amazonian rainfall.

In summary, Henderson-Sellers and Pitman (2002) provide corroborating evidence for our findings on interdecadal trends of Amazon precipitation. They raise some interesting questions on internal mechanisms relating to Amazonian precipitation that can and should be tested in other deforested regions in addition to the Amazon basin. However, they do not dispute or shed new light on the focus of our paper that the *global* circulation changes over the past 40 years has enhanced *global-scale* convergence into the region and is likely the dominant cause of the observed precipitation increase.

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